

## LONG WAVELENGTH, PURE SILICA CORE SINGLE MODE FIBER AND METHOD OF FORMING THE SAME

### *Technical Field*

[0001] The present invention relates to a single mode fiber for long wavelength (e.g.,  $\lambda = 1550$  nm) applications and, more particularly, to a single mode fiber comprising a pure silica core and a relatively thick cladding such that the ratio of the diameter of the cladding (defined as "D") to the diameter of the core (defined as "d") is greater than 8.5.

### *Background of the Invention*

[0002] In single mode optical fibers, a significant fraction of the total guided energy is not confined to the core, and the "tail" of the power distribution extends a considerable distance into the cladding material. Since the substrate (or sleeve) tube material outer cladding is typically less pure (and therefore much more lossy) than the cladding material, it is necessary to ensure that no significant fraction of the total power propagates in the substrate- or tube-derived material.

[0003] In one type of prior art single mode fiber, referred to as a "depressed cladding" fiber, the effective refractive index of the cladding material is chosen to be substantially less than the refractive index of the core. In most of these depressed cladding prior art designs, the core region is "up doped" and the cladding region is "down doped" so as to obtain the largest difference in refractive index with the smallest overall fiber diameter. The ratio of the cladding diameter D to the core diameter d, is useful in determining various performance parameters of optical fiber made from the preform. For example, to obtain optical fiber having desired transmission characteristics, the D/d ratio should be within an acceptable, but relatively narrow, range of values. The D/d value also affects the cut-off wavelength of the drawn fiber. The cut-off wavelength is the wavelength above which the optical fiber behaves as a step-index multimode fiber and below which behaves as a single mode fiber. Also, the D/d ratio affects the mode field diameter (MFD) which is a measure of the width of the light intensity in a single mode fiber - also referred to as the "spot size". In most cases, it is desired to maintain the ratio D/d less than 2.5. While this value is acceptable for most short wavelength

arrangements, longer wavelengths (e.g., 1550 nm) cannot be supported in such an arrangement.

[0004] In the case where a depressed clad/pure silica core fiber is used (i.e., cladding is doped to exhibit a refractive index less than silica, a non-negligible fraction of the total power will leak to the outer cladding. The fiber would thus have relatively high loss, even if the outer cladding has a low absorption loss, comparable to that of the deposited cladding material. This type of loss is referred to as a "leaky mode" loss, since the radiation propagating in the outer cladding is unguided and will "leak" away. Leaky mode loss can be avoided by depositing a significantly thick cladding layer.

[0005] Therefore, for a pure silica core fiber, the depressed cladding which provides the index difference necessary for a waveguide must be large enough to contain the single mode, while not allowing the energy to leak from the fiber and drastically increase attenuation at the specified wavelength. Thus, the preform must be designed to have a cutoff wavelength that is relatively close to the operating wavelength to adequately contain the mode. Further, the depressed cladding material should have a thickness sufficient to contain the operating wavelength mode without suffering from huge bending loss.

### ***Summary of the Invention***

[0006] The present invention addresses the need remaining in the prior art and relates to a single mode fiber for long wavelength (e.g.,  $\lambda = 1550$  nm) applications and, more particularly, to a single mode fiber comprising a pure silica core and a relatively thick cladding such that the ratio of the diameter of the cladding (defined as "D") to the diameter of the core (defined as "d") greater than 8.5.

[0007] In accordance with the present invention, the core is formed from pure silica, with a relatively thick cladding comprising fluorine-doped silica. The addition of the fluorine species serves to reduce the effective refractive index of the cladding material with respect to the pure silica core material. Using conventional MCVD processes, approximately 30-90 layers of fluorine-doped silica are deposited within a glass preform tube, with the core material thereafter deposited over the deposited layers of fluorine-doped silica.

[0008] Advantageously, by forming a fiber with such a large  $D/d$  ratio, the fiber will be radiation resistant - a necessary feature for some applications. The fiber has also been shown to be hydrogen resistant (i.e., performs well in a hydrogen environment) and, therefore, exhibits improved resistance of the hydrogen-induced loss typically seen in harsh environments ("downhole" fibers, for example).

[0009] Other and further advantages and features of the present invention will become apparent during the course of the following discussion and by reference to the accompanying drawings.

### ***Brief Description of the Drawings***

[0010] Referring now to the drawings,

[0011] FIG. 1 illustrates a cross-sectional view and associated refractive index profile for a single mode, long wavelength fiber formed in accordance with the present invention; and

[0012] FIGs. 2 - 5 illustrate an exemplary process for forming the single mode, long wavelength fiber of the present invention.

### ***Detailed Description***

[0013] FIG. 1 contains a cross-sectional view (FIG. 1(a)) and associated refractive index profile (FIG. 1(b)) of a long wavelength, single mode fiber 10 formed in accordance with the present invention. The fiber comprises a relatively small diameter pure silica core region 12, where the diameter of core region 12 is referred to as " $d$ " in the illustrations. A relatively thick cladding layer 14 surrounds core region 12, where the diameter of cladding layer 14 is defined as " $D$ " in the illustrations. In accordance with the present invention, cladding layer 14 is doped with fluorine, which functions to lower the effective refractive index of the material, ensuring that most of the propagating signal will remain in the core region. A "tube" layer 16 is shown as surrounding cladding layer 14, where tube layer 16 may also comprise pure silica. FIG. 1(b) illustrates the refractive index profile for fiber 10, where the difference between the refractive index of the core

(defined as  $n_{12}$ ) and the refractive index of the cladding (defined as  $n_{14}$ ) is shown as “ $\Delta$ ”. Since the inclusion of fluorine in the cladding layer functions to “depress” the refractive index of the cladding, most of the propagating single mode optical signal will be maintained within core region 12. In accordance with the present invention - and contrary to conventional fiber fabrication parameters - the ratio  $D/d$  is controlled to be relatively large, greater than 8.5, and preferably in the range of 9 to 10. For example, for a 10 micron fiber pure silica core, a fluorine-doped cladding would necessary exhibit an outer diameter greater than 85 microns, and preferably in the range of 90 to 100 microns.

**[0014]** FIGs. 2 - 5 illustrate an exemplary process sequence that may be used to form the long wavelength, single mode fiber of the present invention. The process, as shown in FIG. 2, begins with an exemplary glass tube 20 used to fabricate an optical fiber preform using the well-known “modified chemical vapor deposition” (MCVD) technique. Cladding material 22 is then deposited on the inner wall 24 of tube 22, as shown in FIG. 3. The cladding is deposited in a number of layers so as to form the desired thickness for the final preform structure. In some cases, as many as 30 - 90 separate layers of fluorine-doped silica will need to be deposited to form the thick cladding region. In particular, the number of layers is controlled (in combination with various process parameters) with respect to the predetermined diameter  $d$  of the core region to obtain the desired  $D/d$  ratio. During processing, if it is discovered that the cladding is too thick, an HF etch may be used to remove a portion of the deposited cladding material. Depending on the length of glass tube 20, the deposition temperature is preferably within the range of approximately 1920 - 2020 °C. The fluorine-doped cladding is formed from precursors of  $\text{SiF}_4$ ,  $\text{O}_2$ ,  $\text{SiCl}_4$  and He. Depending on the equipment used, half of the layers can be deposited in one direction (e.g., from left to right), with the other half then deposited in the opposite direction (e.g., from right to left) so as to “balance” any irregularities in the geometry of the relatively thick deposited cladding material.

**[0015]** Once a sufficient amount of fluorine-doped cladding material 22 has been deposited, silica core material 24 is deposited on the inner wall 26 of cladding material 22, as shown in FIG. 4. After core material 24 has been deposited, the tube is collapsed to form the preform, as illustrated in FIG. 5. In accordance with the present invention, the thickness of cladding material 22 ( $D$ ) and the thickness of core material 24 ( $d$ ) are

controlled such that  $D/d > 8.5$ . Accordingly, by using a pure silica core region of relatively small diameter and a surrounding relatively thick cladding, a single mode, long wavelength signal (e.g.,  $\lambda = 1550$  nm) can be supported.

[0016] In an alternative embodiment, a first set of cladding layers (for example, the first 20 - 30 layers) that are deposited may comprise phosphorous as well as fluorine, followed by "fluorine-only" layers, where the presence of only fluorine will maintain the hydrogen stability, as mentioned above. Moreover, although MCVD is a preferred technique for forming the fiber preform, any other technique that also is capable of forming a fiber having the desired  $D/d$  ratio may be used.

[0017] Indeed, the present invention is intended to be limited in scope only by the claims appended hereto.